

# Bainbridge Island Nearshore Structure Inventory

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## Abstract

The City of Bainbridge Island conducted a detailed inventory of nearshore structural modifications (e.g. bulkheads, docks, groins) and selected natural shoreline features (e.g. overhanging riparian vegetation) during the summer of 2001. The objective of the inventory was to support the Bainbridge Island Nearshore Assessment and the city's Shoreline Management Master Program update by developing a baseline inventory of existing structural modifications, mapping a detailed regulatory shoreline (i.e. ordinary high water mark), and ground-truthing aspects of the Washington State ShoreZone Inventory (WDNR 2001). Using GPS technology, existing GIS data, and recent Washington State Department of Ecology aerial photography (Ecology 2000), City staff and interns inventoried 53 miles of shoreline by foot, kayak, and motor boat. Detailed attribute information compiled into a GIS database provides both a baseline inventory as well as a research database capable of supporting both land use and natural resource inquiries. The methodology and lessons learned provide a relatively cost-effective model for other jurisdictions and researchers in Washington state and could be complementary to other inventory protocols and datasets. In addition to regular planning and permitting activities, the results of the inventory were used in the Bainbridge Island Nearshore Assessment project to assess human modification and stressors to the nearshore ecosystem. Results also demonstrate both accuracies and inaccuracies of the Washington State ShoreZone Inventory (WDNR 2001).

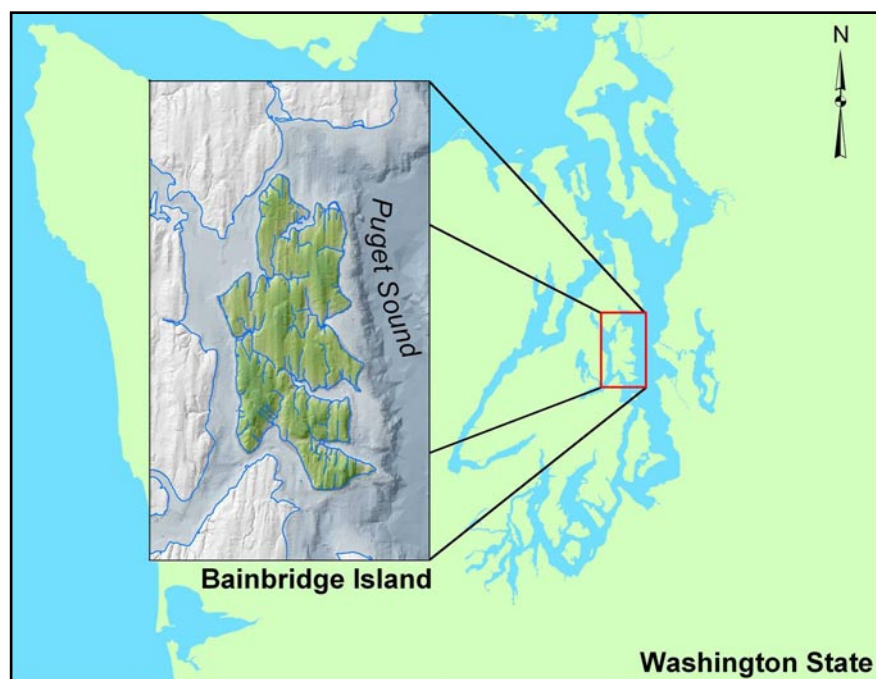
## Introduction

Bainbridge Island is located in the Central Puget Sound adjacent to the Kitsap Peninsula, due west of the City of Seattle (Figure 1). The Island has a population of approximately 20,500 people, a land area of about 28 square miles, and just over 53 miles of shoreline. The Bainbridge Island shoreline is characterized by a diversity of coastal geomorphic settings distributed across exposed open shorelines as well as protected inlets and lagoons.

Bainbridge Island makes for an interesting area of study for many reasons, including that it is a fairly large island with self-contained watershed and shoreline systems, it exhibits both urban and rural shoreline development characteristics, and it is under the jurisdiction of a single local government. As a general pattern, population density is concentrated in the city's urban core located on the northern shore of Eagle Harbor and along much of the remainder of the Island's shorelines. While not a measure of "buildout," approximately 82 to 85% of shoreline parcels have been developed to some extent, but areas of lower densities and park lands remain. Shoreline uses are primarily single-family residential, with commercial and industrial uses concentrated primarily in Eagle Harbor. The Island's shorelines host two state parks and several local parks, a large fish pen aquaculture facility, the Washington State Ferries' Maintenance and Repair Facility, the second busiest ferry terminal in the state, many marinas, and the historic legacy of large sawmills, ship yards, and a federal Superfund site that was a large creosote wood treatment facility (Figures 2-4).

The City of Bainbridge Island has been working on updating its Shoreline Master Program since 2000, which includes a change in management philosophy from primarily managing shoreline uses at site-specific scales to also managing the nearshore ecosystems at landscape-scales. The city also began the Bainbridge Island Nearshore Assessment in 2000, to not only support future salmon habitat restoration and preservation project, but to support the ongoing management of the Island's nearshore. The nearshore ecosystem includes a fairly narrow, but diverse continuum of upland and aquatic areas, including marine riparian, bluff/backshore, intertidal beach, and shallow subtidal zones (Williams et al 2001). The city began two projects following the listing of Puget Sound chinook salmon as threatened under the US Endangered Species Act in 1999 and the release of updated Shoreline Master Program Guidelines by the Washington State Department of Ecology in 2000.

During the summer of 2001, the city conducted a detailed inventory of nearshore structural modifications (e.g. bulkheads, docks, groins) and select biological and geomorphic features (e.g. ordinary high water mark, overhanging riparian vegetation). The objective of the inventory effort was to collect a spatially accurate baseline dataset with detailed descriptive information that could support regular planning and permitting activities as well as a wide range of research inquiries. The inventory data was an essential component of the Bainbridge Island Nearshore Assessment project because it provided the detailed spatial and attribute information that was combined with other natural resource



**Figure 1.** Study Area.



**Figure 2.** Blakely Harbor Park. (© WA Dept of Ecology 1992)

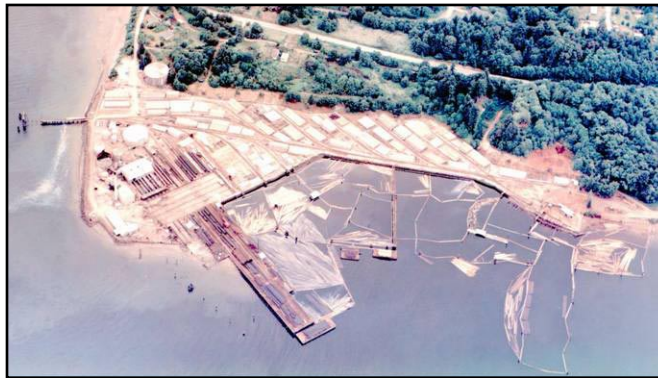
data to characterize and assess the nearshore ecosystem at various landscape-scales (Williams et al 2003; Williams et al, In Prep). The inventory was also an essential component of the city's update of its Shoreline Master Program (i.e. local shoreline management regulations) because the Washington State Shoreline Management Act (RCW 90.58) and the Washington State Department of Ecology's Shoreline Master Program Guidelines (Ecology 2000a; Ecology 2002) require the inventory of land-use patterns, infrastructure, and the extent of existing shoreline modifications.

## Methods

Based on an evaluation of the inventory requirements of the Washington State Department of Ecology Shoreline Master Program Guidelines (Ecology 2000a) as well as budgetary and timeline constraints, the city decided that existing city and state-wide databases provided adequate information about nearshore biology and geomorphology. The city also decided that an inventory of nearshore structural modifications was necessary. As the city began working on designing the Nearshore Structure Inventory, we reviewed several other nearshore inventories, including: Washington State Department of Natural Resources' Washington State ShoreZone inventory (WDNR 2001); People for Puget Sound's Rapid Shoreline Inventory Protocol (PPS 2001); Thurston Regional Planning Council's Inventory and Characterization of Shoreline



**Figure 3.** Washington State Ferries' Repair and Maintenance Facility. (© WA Dept of Ecology 2000)



**Figure 4.** Wycoff Creosote Plant in operation before being designated a Superfund Cleanup Site. (© WA Dept of Ecology 1977)

Armoring (TRPC 1993; Morrison 2001); and an inventory (Kathey 1994) conducted by the City of Bainbridge Island in 1992. These four inventory projects proved very useful for evaluating methods, results, and lessons-learned as well as assessing the value of data collected at different scales.

## Literature Review

The inventories reviewed varied greatly in scope depending on their objectives, budgets, existing data, available technology to conduct field work, store data, and conduct analysis. Inventories also varied in their use of volunteers to do field work. Perhaps the most significant variance between inventory projects and their ultimate usefulness was the scale at which the data was collected and appropriately used for analysis. Scale can be broken down into three categories - spatial, temporal, and depth-of-detail. The spatial scale includes both the geographic extent of the data (i.e. state-wide vs. county-wide vs. parcel) as well as the spatial extent at which the data is useful (i.e. regional vs. landscape vs. site-specific). The temporal scale, as considered here, is the amount of time it takes to conduct the inventory over a geographic area. The depth-of-detail scale is the amount of descriptive information (i.e. attributes) collected about the features inventoried (i.e. present/absent vs. height, width, material, condition, etc.).

The release of the Washington State ShoreZone Inventory (ShoreZone) has provided an exceptionally valuable and unrivaled database that is consistent over Washington State's marine and estuarine shorelines and useful at landscape scales. It has been described as a "coarse filter" that can be used directly at landscape scales or as a guide for data collection at finer spatial and depth-of-detail scales. ShoreZone was conducted by resource professionals via helicopter and GIS analysis to categorize a broad range of nearshore characteristics, including geomorphology, biology, and structural modifications. ShoreZone recorded this data based on linear "units," which represent geomorphically homogenous nearshore areas. The ShoreZone effort was able to fly the field inventory of Bainbridge Island (53 miles)

in approximately 1.5 hours and ultimately documented data across 198 ShoreZone units that ranged in length from approximately 100 feet to 1 mile. Since ShoreZone categorized nearshore characteristics at landscape scales (i.e. ShoreZone units) and very rapid temporal scales (i.e. helicopter flying at 60mph), the depth-of-detail of the attribute information was necessarily limited. ShoreZone categorized most biological data as continuous, patchy, or absent and recorded most shoreline modification data as well as overhanging riparian vegetation as estimated percentage of unit length in ten-percent increments. ShoreZone also enumerated a few specific structural characteristics, including boat slips, piers/docks, and boat ramps. (WDNR 2001)

The Rapid Shoreline Inventory Protocol (RSI) had just finished development and was completing field testing when the city decided to conduct a nearshore inventory. The city was interested in using RSI to do the inventory work, but the timing did not work out. RSI is designed to be able to “nest” with ShoreZone. Through this nesting ability and insisting on a consistent protocol, RSI is capable of producing data at finer spatial and depth-of-detail scales, but can still be appropriately compared at broader landscape and regional scales after data-reduction. RSI is conducted on the beach by trained volunteers and professional staff using categorized field data collection forms at low tides and records data based on linear units of 150 feet. The enumeration of nearshore structures is limited to the four largest structures as well as 3 outfalls. RSI reportedly takes approximately six volunteers and two staff to inventory one mile in a three-hour low-tide window under good conditions. More area could be inventoried per day given more people and/or lower tides. Since RSI relies heavily on volunteers, volunteers are required to participate in 10 hours of training and there are fairly extensive QA/QC procedures. (PPS 2001) When compared with ShoreZone, RSI improves somewhat on the depth-of-detail scale of attribute information recorded for structural modifications and in most cases significantly improves on the spatial scale.

The Thurston Regional Planning Council Inventory and Characterization of Shoreline Armoring was undertaken to map the extent of shoreline armoring and evaluate the rate of shoreline armoring. The Council’s study was conducted during the winter by boat using aerial photos and assessors maps to record the data, which was later digitized into a GIS database. In order to conduct the historical analysis, the Council used permit records and aerial photo interpretation. The Council’s report advised using smaller boats to reduce the observer’s distance from shore and shifting field work to the summer for better conditions. (TRPC 1993)

The 1992 Bainbridge Island shoreline survey was conducted in two phases. The first phase was a video reconnaissance survey that was used for data interpretation and later to QA/QC field data forms from phase two. The second phase was an inventory of nearshore geomorphic, biological, and structural modifications conducted on a single day at the lowest tide of the year by trained volunteers using paper maps, which were annotated and categorized field data collection forms. Teams of two to three volunteers were assigned one of 44 discrete “sections” of shoreline to inventory. Structural modifications were mostly enumerated for the shoreline section, while armoring was estimated as percent of section length in broad increments of mostly 25 percent. (Kathey 1994) Unfortunately, the data collected during this inventory was never transferred to a GIS database and the video, map, and data form records are now incomplete and disorganized. Useful island-wide results are limited to simple summary information mapped to the 44 “sections” and summary lists of observed species.

### **Inventory Design**

After evaluating these four inventories, our timing and budgetary constraints, and our prior evaluation of existing biological and geomorphic data, the city decided to conduct a fairly fast but accurate inventory of all nearshore structural modifications as well as a few limited biological and geomorphic characteristics using City staff and interns. Limiting the inventory in this way avoided the cost of hiring resource professionals, significantly reduced the amount of training necessary for field crews, and allowed the crews to focus on a particular set of inventory items, which significantly increased the speed of their work. Similar to RSI, we wanted to be able to “nest” our data with the Washington State ShoreZone Inventory because our Washington State Salmon Recovery Funding Board grant for the Bainbridge Island Nearshore Assessment required compatibility with state-wide databases when possible. Nesting our data with ShoreZone also allowed us to ground truth the structural modification and overhanging riparian vegetation data contained in ShoreZone, the results of which could be helpful to other jurisdictions when updating their shoreline master programs. It was also decided that we would inventory the ordinary high water mark (OHWM) since it is important for defining the landward extent (200’ from OHWM) of regulatory jurisdiction of local shoreline master programs and prior data depicting OHWM on the Island was known to have a positional accuracy of as much as +/- 100 feet in some areas. We also made sure that our inventory design collected data that was useful to other City departments and compatible with the overall inventory effort. Therefore the inventory resulted in collecting additional data and/or attribute information for the city’s Engineering Department (e.g. surveying monuments, stormwater outfalls) and the Harbormaster (i.e. buoys, boats, pierheads, and navigational aids).

We conducted various types of shoreline reconnaissance to assist in the design of the inventory, including boat trips as well as reviewing copies of the original ShoreZone helicopter videos (WDNR 2001) and Washington State Department of Ecology aerial oblique photographs (Ecology 2000b). After conducting the reconnaissance work, we decided to field-inventory overhanging riparian vegetation, largely because we suspected it was overestimated by ShoreZone. We also suspected that ShoreZone underestimated the amount of total structural modifications. The final list of nearshore features inventoried is presented in Table 1.

The city explored available technology capable of highly accurate and efficient field data collection, which resulted in the selection of high quality backpack GPS systems capable of directly inputting attribute information into a database via handheld keypads, therefore replacing categorized field data collection forms and avoiding the time and errors associated with transferring data from paper into a computer database. One of the GPS systems was rented while the other was loaned to the city by the Washington State Department of Natural Resources. Data from the GPS systems were directly transferable to the city's GIS software, ESRI ArcView 3.2. The two GPS systems used included a Leica GS50 with a Leica Laser Locator (Vector IV) range finder and a Trimble Pathfinder Pro XR, both of which had advertised positional qualities of +/- a few centimeters. Actual in-field positional accuracy, however, was generally +/- 2 feet or better. The Leica range finder used an infrared beam and an electronic compass, plugged directly into the Leica GPS system, and was capable of transmitting both the azimuth and range of the inventory object to the GPS system. The range finder allowed field crews to inventory items from a distance (i.e. from a kayak, boat, or away from a bluff or dense vegetation that blocked satellite reception), but it additively reduced positional quality by +/- 2 meters.

Since the inventory data was expected to have high spatial accuracy, attribute information was strategically designed to support and enhance general shoreline management activities, the Bainbridge Island Nearshore Assessment, and advanced research inquires in contexts that are both spatial (i.e. what is the distribution of armoring along feeder bluffs) as well as relational (i.e. where has there been adverse impacts to beach substrate composition and sediment transport dynamics as evidenced by exposed bulkhead footings, sediment interception, or even perhaps a coarsening of sediments down drift of heavily armored feeder bluffs). Attribute fields, categorization, simplified measurement techniques, the order of data entry, and the use of shortcuts during data entry were also planned to maximize inventory efficiency. The data dictionary that resulted is located in Appendix A.

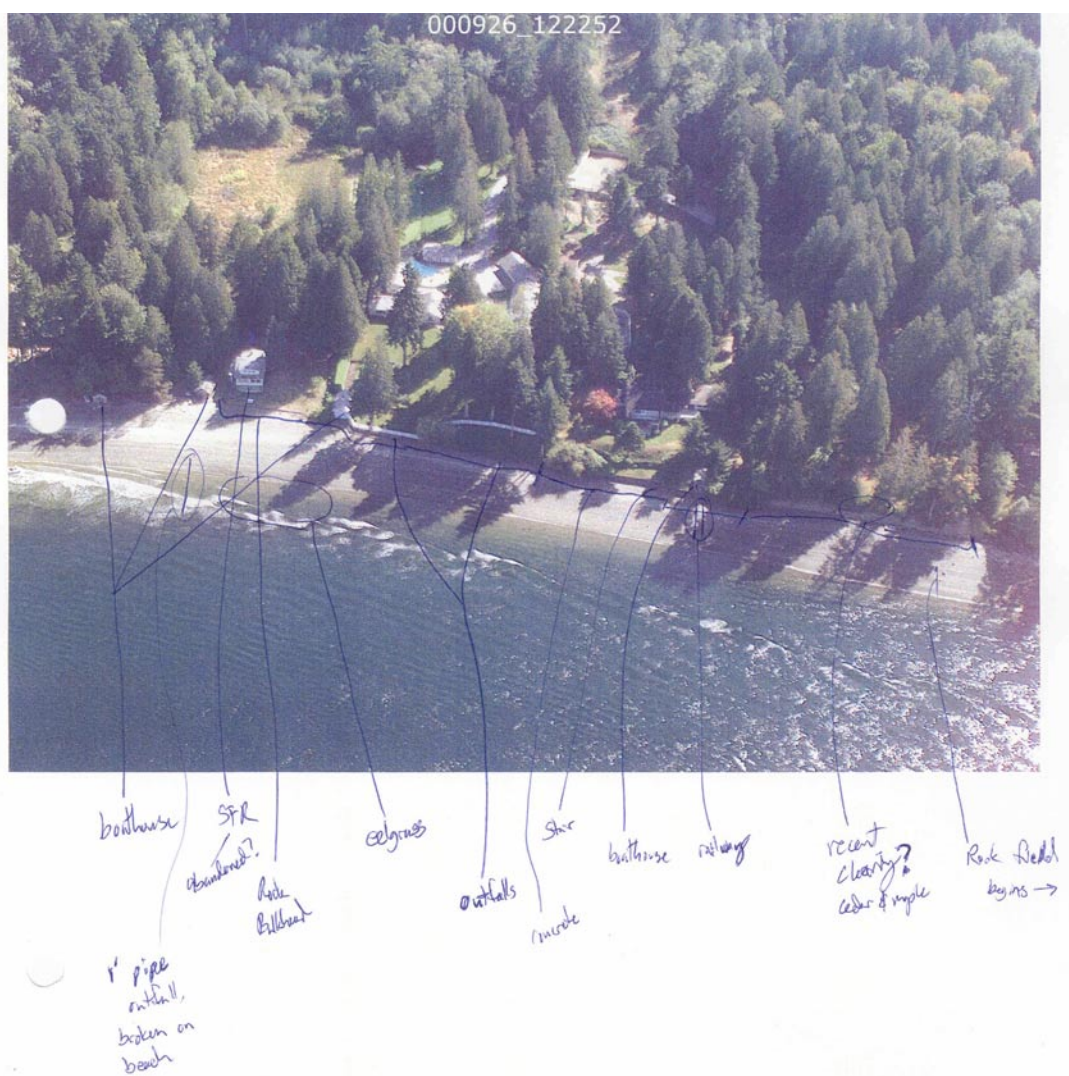
Our inventory methodology called for the field annotation of over 600 digital oblique aerial photographs (Ecology 2000b) that were taken at fairly close range and high resolution. Photographs were annotated to improve photo interpretation, allow for QA/QC of some data, and record changes since the photographs had been taken (Figure 5). Since the city did not own the GPS systems used and had no prior experience with them, all crew members were trained to use the equipment and complete the attribute information correctly. The inventory methods were also field tested.

Unlike the Rapid Shoreline Inventory (PPS 2001) and the 1992 Bainbridge inventory (Kathey 1994), we chose to use a small group of dedicated staff and interns instead of volunteers to do the field work. This was primarily because we had a limited number of GPS systems that were highly technical in nature, the design of the inventory required a substantial time commitment in both hours/day and total number of days, and the added QA/QC demands over 53 miles of volunteer effort would be high. All the inventories reviewed for this project recorded geomorphic and biological data in some cross-shore method, such as distinguishing between backshore, intertidal, and subtidal zones, but unfortunately structural modification data lacked such spatial categorization. One intent of our inventory design was to use our spatial accuracy to allow for cross-shore characterizations and evaluations in later GIS analysis (i.e. what depths do moorages maintain at low tide, are moorages likely in an eelgrass bed, how far do bulkheads trespass into the intertidal zone).

### **Field Work**

We used one field crew per day of two or sometimes three people. Field crews traveled light and fast, stopping only to capture data points and eat lunch. Attribute information associated with each data point was typically entered as the crew traveled between data points. Field crews carried minimal equipment and supplies that could fit into the GPS backpacks. Field work was conducted between mid-August and early-October, taking 31 days for field work and 4-5 days for training and field testing. Data collection was separated into two broad categories, data that could be collected offshore and data that needed to be collected from the beach. The vast majority of data was collected by walking the beach or kayak, which was necessary to identify and record the ordinary high water mark, structures hidden by vegetation, the presence of marsh vegetation, and attribute information like seepage along vegetated bluffs. Piers, floats, buoys, boats, and navigational aids were all collected offshore by motor boat.





**Figure 5.** Field-Annotated Oblique Aerial Photograph (© WA Dept of Ecology 2000)

**Table 1.** Nearshore Features Inventoried (by field-collection method).

Beach/Kayak	Boat
Armoring	Piers
Groins	Floats
Fill	Buoys
Overwater Structures	Boats
Piles	Navigational Aids
Ordinary High Water Mark (OHWM)	
Overhanging Vegetation	
Stairs	
Pollution	
Marine Railways	
Boat Ramps	
Upland Structures within 30' of the OHWM	
Survey Monuments	
Outfalls	

During the first part of the project we had only the Leica GPS system, so one crew member collected inventory data, while the other annotated photographs, answered questions from residents and passers-by, and assisted with data collection (i.e. standing at OHWM holding a range finder target, taking measurements, scouting and calling out attribute information). In addition to the other reasons for annotating the photographs, the technique was useful for avoiding data gaps by identifying the beginning and end points of each days inventory work. We were later able to borrow the Trimble GPS system from the Washington State Department of Natural Resources. Having two GPS systems in the field made data collection much faster because each person could specialize at collecting specific types of data or the two could leap-frog each other as they moved along the beach. One person was still assigned to annotate the oblique aerial photographs and all data recorders kept field notebooks. Crews were able to cover up to 3-4 miles per day collecting data along the beach.

Unfortunately, we discovered nearly half way into the project that the range finder's electronic compass had been set to magnetic north instead of true north, which resulted in a 21.5 degree error for all data collected using the range finder. The resulting positional accuracy of these data points therefore decreased with range. This situation presented a difficult problem because we had a mixed dataset - almost half our data was collected using the range finder with the associated error while the rest of the data did not have the error. Because of the GPS software architecture, it was uncertain if the data could be transposed through a post-processing calculation. Therefore, we choose to maintain the existing range finder setting so that the error was consistent if the dataset could not be transposed. In the end, the data could not be transposed. Therefore, the compass error decreased our calculated positional accuracy by an additional +/- 9.3 feet for data collected while beach walking or kayaking and an additional +/- 18.7 feet for data collected by boat. Ultimately, the maximum additive error for data collected using the range finder was calculated to be +/- 17.9 feet for data collected while beach walking or kayaking and +/- 27.3 feet for data collected by boat.

Prior to conducting the field work, our reconnaissance work allowed us to evaluate beach passage issues, such as maximum tidal elevation necessary to safely traverse small rocky headlands or areas with dense collections of large woody debris. For Bainbridge Island, we were able to conduct nearly all beach work safely below a maximum tide of +5' or +6' MLLW, which typically gave use a field window of 4-8 hours per day. Inventory planning also included the identification of suitable access and exit points for the beach work, most of which were public road-ends or parks. Inventory areas were selected based on the length of the tidal window and the length of the area to be inventoried between accessible entrance and exit points. Typically, one vehicle was left at the exit point while crews were either dropped off or left a second vehicle at the entrance point. There were some instances where crews walked along roadways back to a vehicle parked at entrance points and two occasions where field crews were dropped off by boat and walked to an exit point. Highly stable double kayaks were used to inventory back bays and harbor areas where beaches were too muddy, too shallow, or otherwise physically inaccessible to walk or use a motor boat. Kayaks proved to provide excellent access into very shallow areas. Data collection by boat was very efficient and the entire Island was covered in just 3-4 days. Crews of one or two were used in addition to the boat operator(s). Boat work was limited to a minimum tide of +8' MLLW to reduce the effect of slack moorage lines on positional accuracy. We were able to use both the city's police boat as well as a volunteer Harbor Steward's boat for data collection.

## **Data Development & Analysis**

Data was downloaded from the GPS systems every day to a PC and backed up to the city's computer network. Data was exported to our GIS software (ESRI ArcView 3.2) for initial QA/QC and combined to track progress. When all the field work was completed, data from each day for each GPS system was processed into combined GIS databases, each representing a specific type of data (e.g. armoring, buoy, overhanging vegetation). Each database was then thoroughly reviewed for completeness, numerical categorizations were converted to text (e.g. armoring material categorized as type "1" was converted to "rip-rap"), and some data had to be converted from point features to linear features. This latter conversion was required because most linear features, such as armoring, were field-collected as point data to either improve the efficiency of data collection or because the capabilities of the range finder made linear data collection difficult.

Due to the positional accuracy lost from using the range finder, we choose to simplify the spatial representation of some of the data (e.g. groins, overwater structures) by using points rather than linear or polygonal shapes. Armoring, overhanging vegetation, and ordinary high water mark were retained as linear features. Completed databases were then compared to oblique aerial photographs and digital orthophotos. Based on this final QC/QA process, corrections were made and additional shoreline features were added to the database as appropriate using the photographs to guide editing and digitizing. Most significantly, overhanging riparian vegetation was digitized using a combination of field data and photo interpretation because field crews were often so focused on inventorying structural modifications, they often

missed the vegetation that was literally hanging over their heads. Analysis done for this paper included comparisons with ShoreZone and summary calculations. The majority of the data analysis will be conducted as part of the Bainbridge Island Nearshore Assessment (Williams et al. in prep).

## Findings

We set out to inventory nearshore modifications with a high level of accuracy along spatial and depth-of-detail scales. Even though our data did not meet our spatial accuracy expectations, the data collected is still more spatially accurate and contains more detailed attribute information than existing City data and remains capable of supporting most of the spatial and relational analysis we intended.

### Summary Inventory Results

The Bainbridge Island Nearshore Structure Inventory resulted in the most accurate representation of the ordinary high water mark in the Island's history, totaling 53.45 miles. Riparian vegetation overhangs the ordinary high water mark for a total of 14.5 miles and 26 miles are armored. The inventory also documented, for example: 784 armoring structures, 128 groins, 534 buoys, 42 marine railways, 133 outfalls greater than 8 inches in diameter, 189 piers, 332 floats, 108 boat ramps, and 345 upland structures located within 30 feet of the ordinary high water mark.

Initial analysis of the attribute information collected begins to show interesting characteristics of the nearshore structural modifications around the Island. Of all the armoring structures, only 24 were soft-shore type structures and 15 were revetments. Armoring structures around Bainbridge Island ranged in length from 2 to 2,000 feet, have an average height of 5.5 feet, and have an average water line height of 2 feet, which indicates that a typical bulkhead stands in 2 feet of water at approximately mean high tide. Conversely, 83 armoring structures are set far enough back from the water to allow marsh vegetation to grow at their base and 126 armoring structures are set far enough back to allow large woody debris to accumulate. Of all the armoring structures, 86 have exposed footings, 150 have suffered some sort of damage, and 59 have failed in some way. Combined tabulation of inventory data shows that 152 structures (e.g. groins, floating docks, marine railways, boat ramps) intercept long-shore sediment drift. There are a total of 1,515 moorings associated with piers, docks, marinas, and buoys. A net calculation of all piles associated with piers, docks, other structures, and standing alone total 6,439.

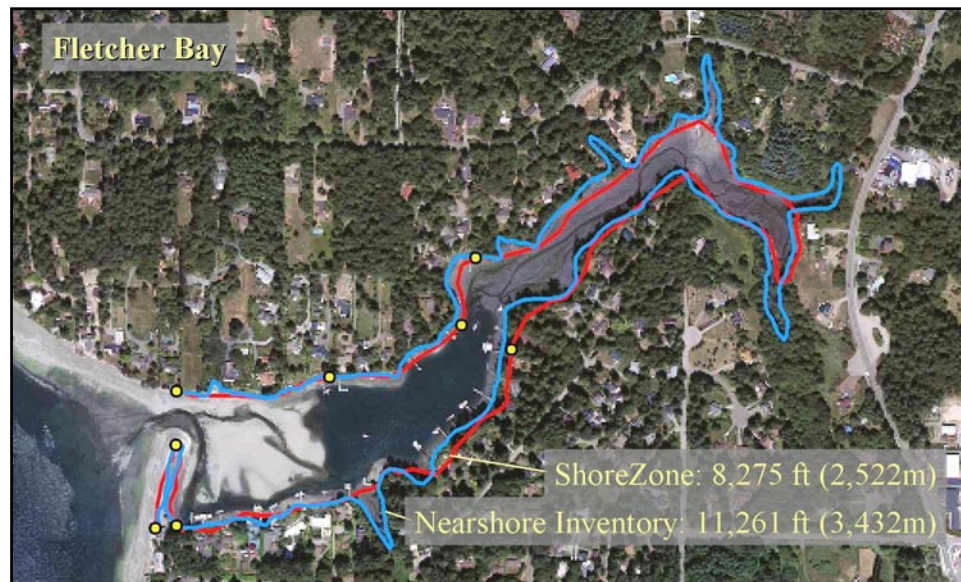
### ShoreZone Ground Truthing

Since the Bainbridge Island inventory was designed to "nest" with ShoreZone, we were able to ground truth some of the ShoreZone data, including shoreline modifications (i.e. armoring, fill, boat ramps), moorage slips, piers/docks, boat ramps, and overhanging riparian vegetation. ShoreZone categorized total shoreline modification and overhanging riparian vegetation as percentage estimates of total unit length in ten-percent increments and enumerated moorage slips (not including buoys), piers/docks, and boat ramps. As shown in Table 2, ShoreZone documented significantly fewer (n=64) piers/docks. ShoreZone also documented more (n=100) small moorage slips, which is confounding due to ShoreZone's undercount of piers/docks but may be the result of differing observer techniques for counting small slips. ShoreZone also documented significantly fewer (n=96) boat ramps, which was likely the result of criteria limited to fairly substantial concrete boat ramps. Because the city was interested in evaluating the number and density of locations where launching activity was taking place, we inventoried all shoreline modifications that were clearly used as boat ramps, many of which were made of wood or dirt/gravel/beach materials.

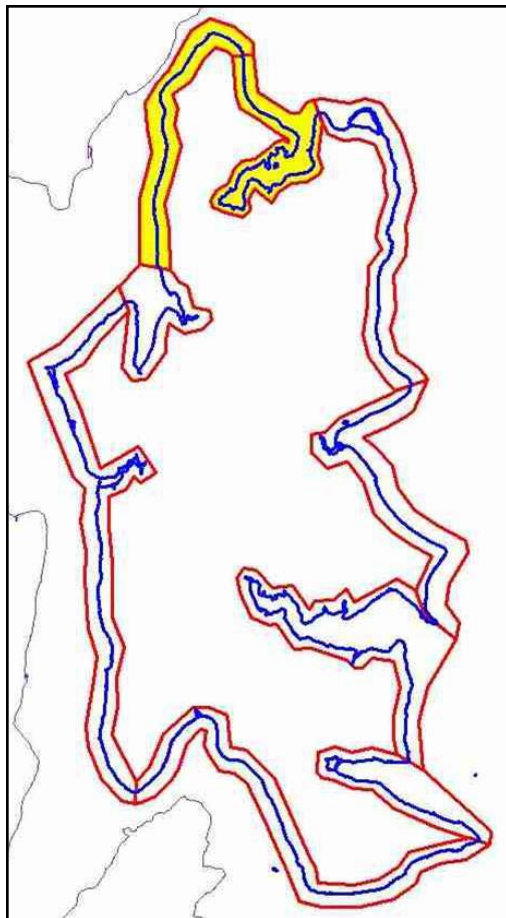
**Table 2.** Summary Inventory Comparison.

	<b>ShoreZone Inventory</b>	<b>Bainbridge Island Inventory</b>	<b>Difference</b>
Shoreline Length	48.59 miles	53.45 miles	-4.86 miles
Shoreline Modification	52.4%	48.5%	3.9%
Overhanging Riparian Vegetation	17.6%	27.1%	-9.5%
Piers/Docks	227	291	-64
Small Moorage Slips (piers/docks only)	1073	967	106
Large Moorage Slips (piers/docks only)	14	14	0
Boat Ramps	32	108	-76





**Figure 6.** Comparison of Shoreline lengths.



**Figure 7.** Areas of detailed comparison (highlighted)

Considering that ShoreZone used 10 percent increments for classification, ShoreZone appears to have fairly accurately estimated total shoreline modifications and underestimated overhanging riparian vegetation at first comparison. But with almost 5 miles difference in the total shoreline length, largely due to the significant sinuosity of the ordinary high water mark (OHWM) inventoried by the city, there was concern that the small jogs along the OHWM could either dilute or overemphasize the city's results when directly compared to ShoreZone (Figure 6). Therefore, the city's data was normalized to the ShoreZone shoreline by transposing beginning and end points of the city's data and recalculating the length of the ShoreZone shoreline between those two points. This data normalization required hand digitization, so the comparison was limited to 36 ShoreZone reaches within two of the city's Shoreline Management Areas (Williams et al. 2003; Williams et al. in prep), one of which was an area of open shoreline with less variance between the shapes of the two shorelines while the other was an embayment with greater variance between the two shorelines (Figure 7).

As shown in Table 3, the differences between ShoreZone and Bainbridge Island data on shoreline modifications and overhanging riparian vegetation is greater within the embayment (Port Madison Bay) where variance between the shape of the two shorelines is greater. However, the difference between the original Bainbridge Island data and the normalized data within either Management Area does not lead to any significant variance or conclusions. Therefore, the effect of a more sinuous shoreline does not appear to significantly influence the direct comparison between data collected in the Bainbridge Island inventory and ShoreZone. At the larger Island-wide landscape, ShoreZone appears to reasonably estimate total shoreline modification. But within the embayment, ShoreZone's inventory by helicopter appears to overestimate total shoreline modification in areas with more complex shoreline shapes. Comparisons within additional geographical areas would be required to conclude this. It appears to be a reasonable conclusion that ShoreZone underestimates overhanging riparian vegetation.

**Table 3:** Detailed Comparison between ShoreZone (SZ) and Bainbridge Island (BI) Inventories.

	SZ Data	BI Data	Normalized to ShoreZone	Difference between normalized and BI	Difference between SZ & BI
<b>Agate Passage (12 SZ reaches)</b>					
% Modified	61.0%	57.3%	56.1%	1.2%	3.7%
% Riparian	32.0%	36.3%	37.6%	-1.3%	-4.3%
<b>Port Madison Bay (24 SZ reaches)</b>					
% Modified	69.1%	61.9%	65.3%	-3.4%	7.2%
% Riparian	17.8%	25.8%	26.0%	-0.2%	-8.0%
<b>Island-Wide (198 SZ reaches)</b>					
% Modified	52.4%	48.6%	n/a	n/a	3.8%
% Riparian	17.6%	27.1%	n/a	n/a	-9.5%

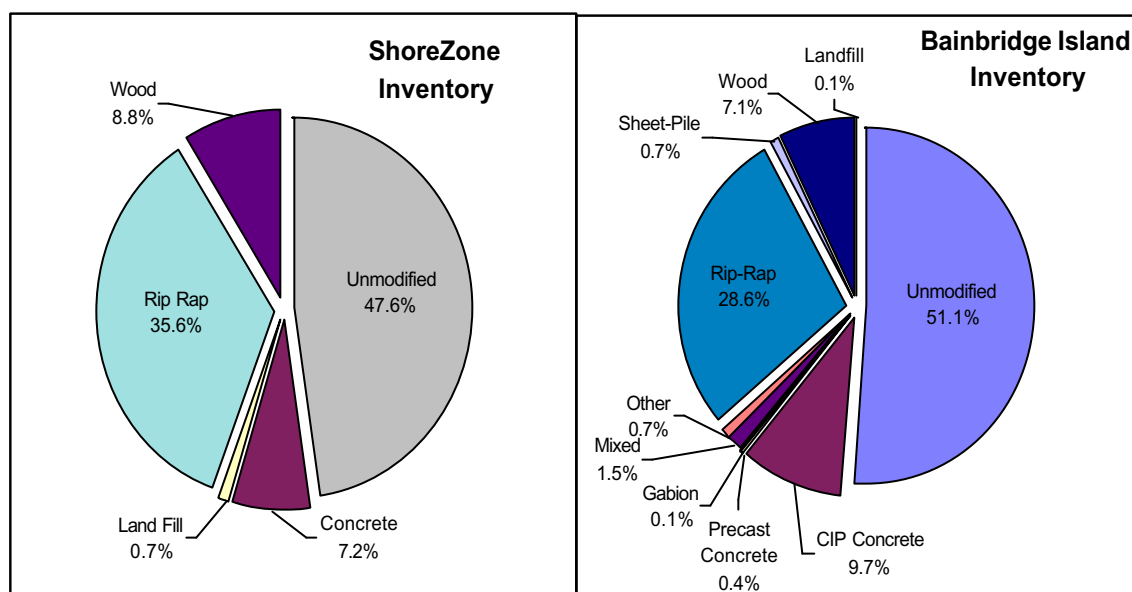
**Figure 8.** Detailed Comparison of Shoreline Modification.

Figure 8 provides a closer look at the ground truthing of shoreline modifications as documented by ShoreZone. ShoreZone documented primary, secondary, and tertiary shoreline modifications as percentage estimates of total unit length in ten-percent increments, which were used to calculate relative linear lengths. While a direct comparison is not appropriate because ShoreZone was restricted to the three most prevalent types of shoreline modifications, it seems appropriate to identify that there are noticeable overestimates of landfill and rip-rap and a noticeable underestimate of concrete-types. These discrepancies, however, do not seem adequate to raise significant suspicions in the total shoreline modification estimates of ShoreZone at broader landscape scales. Further comparison at the individual ShoreZone “unit” scale would provide a more thorough picture of ShoreZone variability and appropriate landscape-scale reliability.

### Conclusions and Recommendations

Nearshore inventories vary greatly depending on existing data, objectives, available technology, and budget. The most important considerations for inventory design include the scales at which the data is collected and useful. The City of Bainbridge Island chose to conduct a focused and highly detailed inventory of nearshore structural modifications and selected biological and geomorphic characteristics. Even though the spatial accuracy of our resulting data was

significantly less than expected, it remains the most detailed and accurate nearshore inventory for the Island and will still be useful for most of the spatial and relational analysis for which it was collected. It will also be useful into the future because it was well designed, stored in a convenient and useful media (GIS database), and will not likely be forgotten or lost because it will be used on an ongoing basis. It is hoped that we will use it as a baseline to conduct historic and future trend analysis like was done by the Thurston Regional Planning Council (TRPC 1993; Morrison 2001) and it will hopefully be used in other ways unanticipated today. Even though we have not calculated the detailed cost of the project, we feel that it was generally cost-effective. We also feel that there is great value in having conducted some level of ground truthing of the Washington State ShoreZone Inventory. With further analysis of data collected in this effort, a more thorough evaluation of ShoreZone data could be achieved.

There are several lessons learned and recommendations that follow for the benefit of others who may wish to pursue a similar effort. Most importantly, we should have become more familiar with our equipment to ensure that it was thoroughly and correctly configured. It would also have been more efficient to use more than one crew, but there is always a risk that different crews will reduce data consistency, especially when changes to procedure are required to deal with in-field conditions. Field reconnaissance was useful, but not necessary if you have good photographic or video documentation.

The Washington State Department of Ecology oblique aerial photographs (Ecology 2000b) proved to be a very good method for interpreting overhanging vegetation and the more obvious nearshore structures when combined with good digital orthophotos. When photo interpreting overhanging vegetation, we would recommend a few broad categories at most be used to categorize the width of overhang and the person conducting the photo interpretation train their skills by taking the photos into the field to learn how certain types of vegetation appear in the light, contrast, and angle of the photos. Fine scaled land cover analysis using more advanced remote sensing techniques may also be useful. The oblique aerial photos may also be useful to approximate ordinary high water mark in some areas. These photographs are not appropriate, however, to remotely inventory features such as armoring, outfalls, stairs, boat ramps, buoys, boats, floats, pollution, overwater structures, and piles. For these features and for nearly all of the attribute information collected, it is necessary to approach and evaluate the feature.

Finally, we designed the inventory so that it would complement biological and geomorphic inventory protocols, such as the Rapid Shoreline Inventory. For those who want more detailed biological and geomorphic data, we would recommend using a parallel crew (i.e. much like ShoreZone used a separate geomorphologist and biologist in the field) to collect that information along side the structure inventory crew to maintain efficiency and avoid missing certain types of data like our overhanging riparian vegetation experience.

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City of Bainbridge Island  
Nearshore Structure Inventory  
Data Dictionary  
*May 2003*

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This data dictionary represents the data collected by the City of Bainbridge Island during August through September 2001. "Shore Data" was collected mostly by foot walking the beach. In areas where the beach was inaccessible by foot (mud or too narrow and steep for safe passage between tides) kayaks were used. Field crews found that safe tides varied around the island due to headlands, large woody debris, and shore slope. In no case was safe passage guaranteed above +5' or +6' MLLW. "Boat Data" was collected by motor boat over the course of several days at tidal elevations of +8' MLLW or higher. Due to some unique circumstances, some Shore Data was collected with Boat Data and visa versa. Data was collected as points to speed up field collection, conversion to linear formats was made using ESRI ArcView (version 3.2 or 8.2). Data was collected using a Leica GS50 GPS system with a Leica Laser Locator (Vector IV) range finder or a Trimble Pathfinder Pro XR GPS.

The data associated with this project is publicly available from the City of Bainbridge Island Department of Planning and Community Development.

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For more information on the methodology and results of this project, see:

Best, P.N. 2003. Bainbridge Island Nearshore Structure Inventory, **In:** Puget Sound Water Quality Action Team. In Prep. *Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference*. T. Droscher, editor. Puget Sound Water Quality Action Team: Olympia, Washington.

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**Notes:**

- ❖ All measurements are recorded in decimal US Feet (i.e. 6" = 0.5').
  - ❖ Data Dictionary Format:
    - Nearshore Feature** (data type) – description
    - Attribute (field type, field characteristics) – description
      - 1. Predefined categories
- 

**Shore Data**

**Armor** (point) – Defensive structures to protect land/structures against the erosive action of waves. [Note: In addition to the attribute collected below, it would have been good to collect seep, clearing, bluff height, and dominate vegetation like was done for shoreline.]

Left/Right (char, mandatory) - Is the data point the left end, middle, or right end when looking landward?

L = left end

M = middle

R = right end

Type (list, mandatory) – What type of armoring is it?

1. Vertical bulkhead (default)
2. Revetment – armoring designed with a sloped back face.
3. soft shore – things like cabled logs, gravel/sand placement

Mean Height (num, default=0) – Average height of bulkhead above the face of the beach.

Angle (list, mandatory) – What is the angle of the bulkhead face?

1. ~90 (default)
2. ~45-90
3. ~45
4. ~<45

Material (list, mandatory) – What type of material is it build out of?



1. Rip-Rap – rocks piled in a wall
2. CIP Concrete – cast in place concrete (single smooth face)
3. Precast Concrete – blocks of concrete somehow held together
4. Wood – any type of wood (plank, piles, RR ties, etc...)
5. Plastic – perhaps recycled material or other plastic
6. Gabion – mesh basket filled with rocks
7. Mixed – combination of these (linear only, if one in front of the other, make a note).
8. Other – something else? Make a note of it in the field note book!

Exp\_footing (num, default=3) – Is the footing of the armoring exposed anywhere?

- 0 = No
- 1 = Yes
- 3 = Unknown

Erosion\_Behind (num, default=3) – Is there noticeable erosion behind the armoring?

- 0 = No
- 1 = Yes
- 3 = Unknown

Damage (num, default=3) – Is the armoring damaged anywhere (cracks, big chips, etc...)?

- 0 = No
- 1 = Yes
- 3 = Unknown

Failure (num, default=3) – Has the armoring failed anywhere so that it can no longer protect from erosion?

- 0 = No
- 1 = Yes
- 3 = Unknown

Mean\_H2O\_ln (num, default=0) – If a water line can be identified, what is the mean height above the beach face at the base of the armoring?

H2O\_ln\_type (list) – what type of line did you measure for mean\_H2O\_ln?

1. color
2. barnacle
3. scum

Marsh vegetation (num, default=3) – Is there marsh type vegetation in front of the bulkhead?

- 0 = No
- 1 = Yes
- 3 = Unknown

LWD (num, default=3) – Large woody debris is resident drift wood or downed trees (or parts of trees) that will not be moved by tides on a daily basis, but may be moved on an annual or semi-annual basis. Ask yourself, will this wood move with the next high tide? If the answer is “no,” consider it LWD.

- 0 = No
- 1 = Yes
- 3 = Unknown

Note (text)

**STRover** (point) – over water structures like houses or decks. May be on pilings or cantilevered.

Type (list, mandatory) – What type of overwater structure is it? If it is a boathouse on pilings but not associated with a pier, than count it here – otherwise, it’s a pier.

1. Deck – This is different than a pier! The distinction is based on size (pier is used for bringing a boat up to at an appropriate tide, a deck could only be used for viewing).
2. House - residence
3. Boathouse
4. Other – make a note of it in the field book!

Total\_Pilings (num, default=0) – Total number of pilings supporting the structure

Num\_wood\_Pilings (num, default=0) – Total number of pilings that are wood

Material (list) – What type of material are the pilings?

1. Wood
2. concrete
3. steel
4. plastic
5. mixed w/ wood
6. mixed, no wood

Note (text)

**Fill** (point) – Foreign material at or beyond the OHWM that is not retained by a bulkhead.

Left/Right (char, mandatory) - Is the data point the left end, middle, or right end when looking landward?

L = left end

M = middle

R = right end

Material (list) – What type of fill material is it?

1. soil
2. construction debris
3. trash
4. other – Make a note of it in the field notebook!

Note (text)

**Groin** (point) – Perpendicular finger type structure designed to trap sediment from moving down the beach.

Material (list, mandatory) – What type of material is the groin made out of?

1. Concrete
2. Rock
3. Mixed
4. Other – Make a note of it in the field notebook!

Drift\_interception (num, default=3, mandatory) – Is there a difference in beach elevation on either side or a difference in grain size of beach material (i.e. sandy on one side and cobble on the other)?

0 = No

1 = Yes

3 = Unknown

Exp\_footing (num, default=3) – Is the footing of the groin exposed anywhere?

0 = No

1 = Yes

3 = Unknown

Damage (num, default=3) – Is the groin damaged anywhere (cracks, big chips, etc...)?

0 = No

1 = Yes

3 = Unknown

Failure (num, default=3) – Has the armoring failed anywhere so that it can no longer protect from erosion?

0 = No

1 = Yes

3 = Unknown

Note (text)

**Monument** (point) – Datum/survey monument

Point\_ID (text) – name of monument

Owner (list)

1. NGS
2. USGS
3. State
4. Tidal-USCGS
5. Other – make note of it in the field notebook!

Datum (list) – what datum is the monument tied to?

1. NGVD29
2. NGVD88
3. Other

Depth (num, default=0) – depth below mud line (if above then use negative (-) number)

Note (text)

**Outfall** (point) – the point at which water is released into another receiving water body. Channels count, even if they are currently dry.

Type (list-mandatory) – What type of outfall is it?

1. Pipe
2. Natural
3. Other – Make a note of it in the field notebook!

Material (list) – If not natural, what type of material is the outfall?

1. steel
2. plastic
3. wood
4. concrete
5. other – Make a note of it in the field notebook!

Flowing (num, default=3) – is the outfall currently flowing?

- 0 = No  
1 = Yes  
3 = Unknown

Erosion (num, default=3) – is the outfall causing erosion, such as a deep channel, cut bank, etc...?

- 0 = No  
1 = Yes  
3 = Unknown

Deposition (num, default=3) – is the outfall depositing material?

- 0 = No  
1 = Yes  
3 = Unknown

Marsh Veg (num, default=3) – is their marsh type vegetation near the mouth of the outfall?

- 0 = No  
1 = Yes  
3 = Unknown

Diameter (num, default=0) – what is the diameter of the pipe outfall or width of channel for stream (bank-full)?

Note (text)

**Pilings** (point) – for groups of piles not associated with a structure. Count piles that are noticeable at or near mud line. Only one point per group is necessary.

Total\_Num (num, default=0) – best approximation of total number of pilings

Num\_Wood (num, default=0) – best approximation of total number of wood pilings

Material (list) – type of piling material

1. wood
2. concrete
3. steel
4. plastic
5. mixed w/ wood
6. mixed, no wood

Nav\_Haz (num, default=3) – are they a navigation hazard (i.e. think of a Jet Ski nearshore)?

- 0 = No  
1 = Yes  
3 = Unknown

**Point\_of\_Interest** (point) – noteworthy point of interest

Note (text)

**Pollution** (point)– indicators of potential pollution.

Type (list) – what type of pollution indicator did you see?

1. sheen
2. odor
3. other – Make a note of it in the field notebook!

Note (text)

**Railway** (point) – railways have two or more tracks (not necessarily steel) and are not solid slabs like ramps.

Elevated (num, default=3) – is the railway elevated on pilings or some other non-solid support that might allow for sediment drift?

- 0 = No  
1 = Yes  
3 = Unknown

Support\_Mat (list) – what type of material are the supports?

1. wood
2. rock
3. concrete
4. steel
5. plastic
6. mixed w/ wood
7. mixed, no wood

Drift\_interception (num, default=3, mandatory) – Is there a difference in beach elevation on either side or a difference in grain size of beach material (i.e. sandy on one side and cobble on the other)?

- 0 = No  
1 = Yes  
3 = Unknown

Abandoned (num, default=3) – is the structure not usable anymore?

- 0 = No  
1 = Yes  
3 = Unknown

Note (text)

**Ramp** (point) – boat ramp of any size.

Material (list) – what type of material is used for the ramp beyond high tide/ OHWM?

1. concrete
2. beach
3. other – Make a note of it in the field notebook!

Drift\_interception (num, default=3, mandatory) – Is there a difference in beach elevation on either side or a difference in grain size of beach material (i.e. sandy on one side and cobble on the other)?

- 0 = No  
1 = Yes  
3 = Unknown

Elevated (num, default=3) – is the ramp elevated on pilings or some other non-solid support that might allow for sediment drift?

- 0 = No  
1 = Yes  
3 = Unknown

Abandoned (num, default=3) – is the structure not usable anymore?

- 0 = No  
1 = Yes  
3 = Unknown

Note (text)

**Stair** (point) – inventory all stairs that physically contact the beach. [Note: This category failed to collect path access and stairs that terminated above the beach like on top of a bulkhead. It would be recommended that all access to the beach be identified.]

Orientation (list) – note the direction the stairs go in relation to the shoreline.

1. parallel
2. perpendicular
3. free standing

Material (list) – what type of material are they?

1. wood
2. concrete
3. metal
4. plastic
5. stone/rock
6. other – Make a note of it in the field notebook!

Inset (num, default=3) – are the stairs inset into the face of a bulkhead?

- 0 = No  
1 = Yes  
3 = Unknown

Note (text)

**USAWL** (point) – Upland structure at water line (i.e. within 30 feet of the water line). These may include boathouses, single family residences, storage sheds, decks, etc...

Type (list, mandatory) – what type of structure is it?

1. boathouse
2. deck
3. SFR – single family residence
4. other – Make a note of it in the field notebook!

Setback (num) - how far back is the structure horizontally from the shoreline?

Note (text)

**Shoreline** (point)– Approximate ordinary high water mark. Collect approximately every 150 feet or as necessary, including at structure breaks if segments are shorter than 150 feet.

Dominate\_veg (list, mandatory) – Dominate vegetation type, include vegetation on the top, face, and toe of a slope.

1. Coniferous Trees
2. Deciduous Trees
3. Shrubs
4. Grass
5. Bare

Bluff\_Height (num, default=0) – Approximate height of bluff by sight or range finder. [Note: this could be replaced with LiDAR derived heights.]

LWD (num, default=3) – Large woody debris is resident drift wood or downed trees (or parts of trees) that will not be moved by tides on a daily basis, but may be moved on an annual or semi-annual basis. Ask yourself, will this wood move with the next high tide? If the answer is “no,” consider it LWD.

- 0 = No  
1 = Yes  
3 = Unknown

Clearing (num, default=3) – Identifiable stumps and/or debris from clearing activity.

- 0 = No  
1 = Yes  
3 = Unknown

Seep (num, default=3) – Is the bluff face wet when it is not raining?

- 0 = No  
1 = Yes  
3 = Unknown

Note (text)



- Overhanging** (point) – vegetation overhanging the beach from the shoreline. Collect at beginning and end of each area (collect new line for major vegetation changes)
- Left/Right (char, mandatory) - Is the data point the left end, middle, or right end when looking landward?  
L = left end  
M = middle  
R = right end
- Mean\_overhang (num, default=0) – how far does the vegetation overhang the beach from the shoreline? [Note: this data could have been collected by photo interpretation instead and should have been categorized into a few width categories, rather than measured width.]
- Coniferous (num, default=3) - are the majority of the plants coniferous?  
0 = No  
1 = Yes  
3 = Unknown
- Native (num, default=3) – are the majority of the plants native?  
0 = No  
1 = Yes  
3 = Unknown
- Note (text)
- 

#### **Boat Data**

- Buoy** (point) – mooring buoy
- Use (list) – How is the buoy used?  
1. Private  
2. Commercial (i.e. tugs, barges)  
3. Public (i.e. ferries)  
4. Unknown
- Height (num, default=0) – Height above the waterline
- Surname (text) – If buoy is labeled with owner surname
- State\_ID (text) – WN#
- Reflectors (num, default=3) – Does the buoy have reflectors?  
0 = No  
1 = Yes  
3 = Unknown
- Note (text)

**Boat** (point) – boat moored to buoy, raft, or small recreational float. Not moored at marina or pier.

- Moorage\_type (list)  
1. Anchor  
2. Buoy  
3. Recreational Float  
4. Other
- Use (list) – How is the boat used?  
5. Private  
6. Commercial (i.e. tugs, barges)  
7. Public (i.e. ferries)  
8. Unknown
- Length (num, default=0) – Length of boat
- WN# (text) – WN or US ID number
- Name (text) – Name of boat
- Tab# (text) – License tab number
- Note (text)

**Pier** (point) – Structures supported by pilings. GPS most waterward end of structure.

Total\_Num (num, default=0) – best approximation of total number of pilings

Num\_Wood (num, default=0) – best approximation of total number of wood pilings

Material (list) – type of piling material

7. wood
8. concrete
9. steel
10. plastic
11. mixed w/ wood
12. mixed, no wood

Structure (list) - Is there a structure on top of the pier? Houses are counted as structures over water, not structures on piers.

1. Boathouse
2. Storage
3. Other

Structure\_height (num, default=0) – What is the height of the structure above deck?

Grated (num, default=3) - Is the deck partially or completely grated (or other light transmitting material)?

- 0 = No  
1 = Yes  
3 = Unknown

Condition (list) – What kind of condition is the pier in?

1. Good (functional)
2. Poor (poorly or not functional)

Small\_slip (num, default=0) – How many slips (50' or less) are there?

Large\_slip (num, default=0) – How many slips (100' or greater) are there?

Note (text)

**Float** (point) – Floating structures, may be attached to piers or anchored out. GPS most waterward end of structure.

Structure (list) - Is there a structure on top of the pier? Residential houses are counted as structures over water, not structures on piers.

4. Boathouse
5. Storage
6. Other

Structure\_height (num, default=0) – What is the height of the structure above deck?

Drift\_interception (num, default=3, mandatory) – Is there a difference in beach elevation on either side or a difference in grain size of beach material (i.e. sandy on one side and cobble on the other)?

- 0 = No  
1 = Yes  
3 = Unknown

Reflectors (num, default=3) – Does the float have reflectors?

- 0 = No  
1 = Yes  
3 = Unknown

Beach\_stops (num, default=3) – Do the pilings have beach stops to prevent the dock from grounding? This may be impossible to collect due to tide height.

- 0 = No  
1 = Yes  
3 = Unknown

Total\_Num (num, default=0) – best approximation of total number of pilings

Num\_Wood (num, default=0) – best approximation of total number of wood pilings

Material (list) – type of piling material

1. wood
2. concrete
3. steel
4. plastic

- 5. mixed w/ wood
- 6. mixed, no wood

Grated (num, default=3) - Is the deck partially or completely grated (or other light transmitting material)?

0 = No

1 = Yes

3 = Unknown

Condition (list) – What kind of condition is the pier in?

3. Good

4. Poor

Small\_slip (num, default=0) – How many slips (50' or less) are there?

Large\_slip (num, default=0) – How many slips (100' or greater) are there?

Note (text)

**Navigation\_marker** (point) – marine navigational aids overwater and on land

Note (text)